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EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER CHARACTERISTICS IN Al_2O_3 – WATER BASED NANOFLUIDS OPERATED SHELL AND TUBE HEAT EXCHANGER WITH AIR BUBBLE INJECTION

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ABSTRACT

Shell and Tube heat exchanger is one of the heat exchangers that are widely being used in industries and in other important commercial purposes. The different techniques have been employed to enhance the thermal or heat transfer performance of shell and tube heat exchanger. Air bubble injection is one such inexpensive, promising and rarely used technique that can improve the thermal performance of heat exchangers. This paper presents the experimental investigation of heat transfer characteristics in shell and tube heat exchanger containing water (distilled) based Al_2O_3 nanofluid with two different volumetric concentration of Al_2O_3 nanoparticles i.e. (0.1%v/v and 0.2%v/v) as a cold fluid inside tube side and distilled water as a hot fluid inside shell side, done by injecting the air bubbles at the tube inlet and at throughout the tube. The results so obtained for the two volumetric concentrations of given nanofluid at two different air bubble injection points were compared with the case, when the air bubble injection was not done. The results showed that the air bubble injection throughout the tube gave maximum enhancement in heat transfer characteristics followed by the air bubble injection at the tube inlet and no air bubble injection. Since the enhancement in heat transfer characteristics varies linearly with the volumetric concentration of nanofluids, nanofluid with 0.2%v/v of Al_2O_3 nanoparticles gave more enhancements in heat transfer characteristics than the nanofluid with 0.1%v/v of Al_2O_3 nanoparicles. Moreover, heat transfer characteristics were also found to be enhanced, when the temperature of hot fluid was increased by keeping the flow rate of both the heat transfer fluids to be constant.

KEYWORDS: Shell and Tube Heat Exchanger, Al_2O_3/Water Based Nanofluids, Effectiveness & Heat Transfer rate

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Original Article

1. INTRODUCTION

In today's era, the limited or confined resources of energy are vanishing day by day as the humans are using them at an unimaginable alarming rate. If the humans continue to use these energy resources in such a rapid rate then the day is not so far when our future generation will starve for these energy resources. This overexploitation of these energy resources has forced the engineers or researchers to find some advanced or new techniques to enhance the thermal performance characteristics of heat exchangers, so that the ever growing demand for these energy resources can be fulfilled to the most possible extent [1].As per the estimation given by the world council, there will be approximately 50% rise in the demand of energy in future, that seems to be very difficult to achieve, if the energy resources usage will remain continue by the humans at the present alarming rate [2]. Heat transfer has a vital role in the world of energy as more efficiency of heat transfer leads to more recovery of heat from the process under consideration, and more the efficiency in recovering the heat will cause more

energy savings. So, heat exchanger is one such device, that can conserve energy by recovering more and more heat with the help of heat transfer process and this conserved energy obtained can be utilized for different purposes. [3].

Out of all the heat exchangers, Shell and Tube heat exchanger is one such commonly used heat exchanger that finds its applications in most industries. This may be due to many factors such as ability to withstand high temperature (from -250°C to 800°C) and high pressure (up to 6000psi) of the working fluid used, easy maintenance and easy manufacturing. The major applications of this heat exchanger is found in industries such as food processing industries, power plants, manufacturing industries, chemical and petrochemical industries etc. Different heat transfer enhancement techniques have been employed to improve the thermal performance of the shell and tube heat exchanger. Air bubble injection technique is one such inexpensive and promising technique for enhancing the heat transfer characteristics in shell and tube heat exchanger. In this technique, air bubbles are injected in to the flowing fluids which move along the fluid leaving behind the void which is filled by the surrounding fluid causing turbulence in the moving fluid which leads to the enhancement in heat transfer rate. Moreover, air bubble injection also reduces the skin friction drag near the wall which also causes the turbulence in the flowing fluid. This method can be applied to enhance the performance of any system involving heat transfer process.[4]

Celeta et al. [5] reported an enhancement in the heat transfer rate by 10 times on studying the effect of air bubble injection at the entrance of a heated channel. Dizaji and Jafarmadar [6] studied the effect of air bubble injection on effectiveness and Nusselt in double pipe heat exchanger. He found 10-40% enhancement in effectiveness and 6-35% enhancement in Nusselt Number.. Gabillet et al. [7] reported an increment in the velocity and turbulence of the flowing fluid when air bubbles were injected in to the flowing fluid. Jiacai et al. [8] explained the phenomena behind the reduction of skin friction drag in boundary layers due to air bubble injection. Mattsonand Mahesh [9] studied the effect of bubble size on the turbulence and revealed that Larger bubble can penetrate to more distance in a turbulent flow while the smaller size bubble just produces effect near the wall or the point of generation. Jacob et al. [10] thoroughly investigated the effect of bubbles and reported that the shear stress and the Reynolds stress near the wall for the two-phase flow have been reduced with the downstream of injection as compared to single phase flow. A.Nandan and G.singh [11] studied the effect of air bubble injection over the heat transfer characteristics in shell and tube heat exchanger and reported enhancement of performance of shell and tube heat exchanger. Kern [12] Introduced first procedure to design a shell and tube heat exchanger. It has been found that the different techniques have been utilized to improve the performance of the shell and tube heat exchangers such as providing fins, different tube geometry, tabulators etc. Studies have been conducted on the effect of baffle height, flow pattern and baffles spacing on the effectiveness of shell and tube heat exchangers [13]. Nanofluids have also been applied to enhance the performance of the heat exchangers. Nanofluid is a fluid that contains suspended solid nanoparticles of metals or non-metals, whose size is generally less than 100nm. Heat exchanger containing nanofluid gives better heat transfer characteristics than heat exchanger containing conventional fluids, because of the fact that the thermal conductivity of solids is better than the liquids. This property of nanofluid having high thermal conductivity than conventional fluids make them future heat transfer fluids in heat exchangers or other suitable thermal equipment [14]. S.M. Fotukian and M. Nasr Esfahany [15] studied the effect of very dilute (less than 0.24% volume) CuO/water nanofluid on the heat transfer coefficient and pressure drop. He found that the inclusion of small amounts of CuO nanoparticles to the base fluid caused a 25 % increase in heat transfer coefficient and a 20 % penalty in pressure drop. Yajie Ren et al. [16] proposed a theoretical model to calculate the effective thermal conductivity of nanofluids considering the effects of an interfacial layer formed between particle and liquid interface and convention (micro) caused by thermal

motion of nanoparticles. The suspended nanoparticle size, volume fraction, temperature and thermal conductivities of the nanoparticle and base fluid were the parameters taken in to account while calculating the enhancement in effective thermal conductivity of a nanofluid. It was found that the predicted results were similar to recently available experimental data. L.Syam Sundar et al. [17] experimentally estimated the thermal conductivity of ethylene glycol and water mixture (50:50) based low volume concentration of CuO and Al_2O_3 nanofluids at different volume concentrations and temperatures. It was found that the thermal conductivity of CuO is more compared to Al_2O_3 under same volume concentration and temperature. K. Rohini Priya et al. [18] studied the thermal conductivity of 0.016 vol% CuO-water nanofluid at 28°C and 55°C and they found the thermal conductivity enhancement of 13% at 28°C and 44% at 55°C. Xiaohao Wei et al. [19] synthesized the water based Cu_2O nanofluids with the help of chemical solution method and experimentally studied the effect of reactant molar concentration and nanofluid temperature on the thermal conductivity. It was found that synthesized nanofluids can enhance thermal conductivity up to 24%. The thermal conductivity also showed sensitivity and non-linearity to the reactant molar concentration and nanofluid temperature.

The objective of this paper is, to find out the effect of air bubble injection on the heat transfer characteristics in shell and tube heat exchangers containing water based Al_2O_3 cold nanofluid with two different volumetric concentrations of Al_2O_3 nanoparticles (0.1%v/v, 0.2% v/v) inside tube side and hot water inside shell side. Earlier studies have shown that air bubble injection technique is never applied to the shell and tube heat exchanger containing nanofluid as one of the heat transfer fluids.

2. NANOFLUIDS PREPARATION

Nanofluids are usually synthesized with two methods namely, one step method and two step method. In this present work, water (distilled) based Al_2O_3 nanofluids with two different volumetric concentrations of Al_2O_3 nanoparticles (0.1%v/v, 0.2% v/v) were synthesized with two step method. 20 nm was taken as the average size of Al_2O_3 nanoparticles. The following equation 1 evaluates the desired or required volumetric concentration of nanoparticles in the water base fluid.

$$\phi = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}} \tag{1}$$

In this research, the nanoparticles of Al_2O_3 were bought from the Nanoshells, DeraBassi, India Company. To prepare Nanofluids, the desired amounts of nanoparticles were allowed to disperse in the water base fluid. The nanoparticles were completely mixed in the base fluid using magnetic stir. In order to remove the agglomerations, nanofluids sonicated in the ultrasonicator for about 2 hours. Since the nanoparticles mixed with the base fluid completely, the addition of surfactant to stabilize the nanofluids was not needed. After completely preparing the both sets of nanofluids, the thermo-physical properties of nanofluids were determined. The thermo-physical properties of nanofluids were determined using the following steps.

3. EXPERIMENTAL SETUP AND PROCEDURE OF WORK

The set up used for the analysis of the experiment is shown in figure 1, and figure 2 shows the schematic diagram of the experimental set up. The experimental set up consists of hot water loop containing distilled water, air injection system, cold water loop containing water based Al_2O_3 nanofluids with two different volumetric concentrations (0.1%v/v and 0.2% v/v) taken one after another and test section.

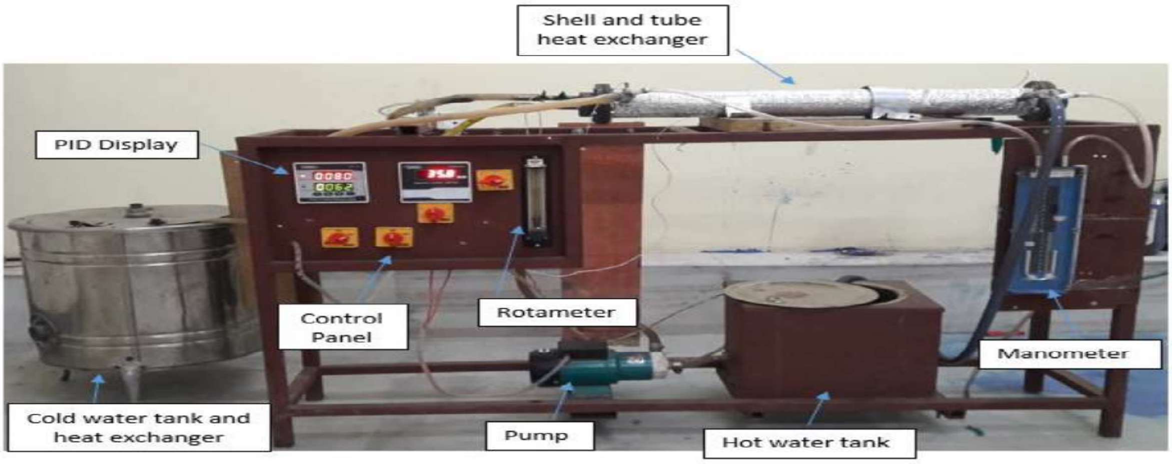

Figure 1: Experimental Setup

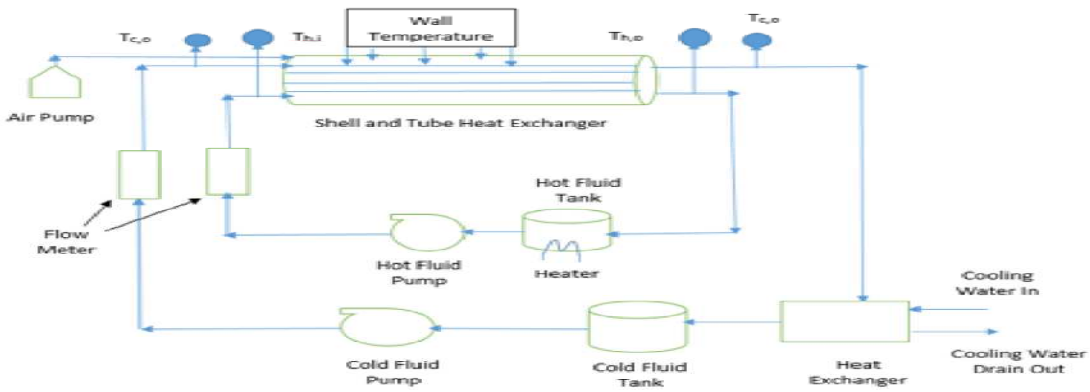

Figure 2: Schematic Diagram of Experimental Set up

Table 1: Shows the Specifications of the Test Section Taken Under Consideration

Table 1: Specifications of Test Section

Dimensions	Value
Length(mm)	600
Shell diameter (mm)	53
Tube inner diameter (mm)	10
Tube outer diameter (mm)	12.5
No of Tubes	4

The K-type thermocouples of accuracy of about ±0.1°C were connected at the inlet and outlet of the tube and shell. To obtain the wall temperature, thermocuouples were also installed on the wall surface of shell and tube heat exchanger. Distilled water is being heated in the hot water tank with five litre capacity. In order to control the temperature

of hot water, a controller known as PID (Proportional-integral-derivative) controller is used. Hot water is pumped to the shell side at variable flow rates (0.5, 1, 1.5, 2, 2.5, 3, 3.5 lpm) and at variable temperatures (30°C, 40°C, 50°C and 60°C).Water based Al_2O_3 cold nanofluid with two different volumetric concentrations of Al_2O_3 nanoparticles (0.1% v/v and 0.2% v/v taken one after another) is being pumped at an invariable flow rate of 3.5 lpm with fixed temperature. In order to regulate the flow rate on both the tube side and shell side, two flow meters were installed on both the sides with an accuracy of about 1%

The range and the accuracy of the components used are shown in table 2.

Table 2: Accuracy of Component

Components	Accuracy
Thermocouples	0.1◦C
Flow meter	1%
PID	0.25%

The aquarium pump was used for injecting the air, with a constant mass flow rate of 0.05833 kg/sec with an almost negligible pressure, as compared to the pressure created by the flow of water at an ambient temperature of 15°C.

Calibration of instruments was done before beginning the test. The experiments were performed in three different scenarios. The first experiment was performed considering water based Al_2O_3 cold nanofluid on tube side and the hot water on the shell side. Distinct readings were noted down at seven regular intervals of time and analysis was done on the basis of the average of the readings taken.

In the second group of experiments, the air and water based Al_2O_3 nanofluid is made to enter the tube inlet. For each case, distinct readings were noted down at seven regular intervals of time and analysis was done on the basis of the average of the readings taken.

The third group of experiments was performed by injecting the air bubbles throughout the tube side carrying water based Al_2O_3 nanofluid and hot water was allowed to flow through the shell side. Before inserting the air bubbles throughout the tube, a very small diameter plastic tube with several holes was inserted inside or throughout the tube. All the above three cases were performed two times, one for 0.1% v/v of Al_2O_3 nanoparticles in the water base fluid and other for 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid.

4. DATA PROCESSING

Heat transfer characteristics such as heat transfer rate and effectiveness are calculated to analyze the effect of air bubble injection technique applied to the shell and tube heat exchanger.

Reynolds number is evaluated by using the following equation (2)

$$\mathrm{Re} = \frac{\rho v d}{\mu} \tag{2}$$

The heat transfer rate is evaluated by using the following equations from (3) – (5)

$$Q_{avg.} = \frac{1}{2}\left(Q_h + Q_c\right) \tag{3}$$

$$Q_c = \dot{m}_c \times C_{pc} \times (T_{c,o} - T_{c,i}) \tag{4}$$

$$Q_h = m_h \times C_{ph} \times (T_{h,i} - T_{h,o}) \tag{5}$$

The effectiveness is given as

$$\in = \frac{Q_{avg.}}{C_{\min} \times \left(T_{h,i} - T_{c,i}\right)} \tag{6}$$

Where

$$C_{\min} = Min(C_h and C_c)$$

$$C_h = m_h \times C_{ph}$$

$$C_C = m_c \times C_{pc}$$

5. RESULTS AND DISCUSSIONS

5.1 Effect on the Heat Transfer Rate

The thermal performance of any heat exchanger is depicted by the amount of heat transferred between the hot and the cold fluid. The heat transfer rate usually occurs due to temperature difference taking place between the hot and the cold side. From the equations (3), (4) & (5), it can be seen that the heat transfer rate is directly proportional to the temperature difference. From the experimental investigation, heat transfer rate was found to be enhanced with the increase in the Reynolds Number. The air bubbles were injected at different points that showed an increment in the heat transfer rate when compared to the case when no air bubble was injected. The air bubbles injected throughout the tube showed maximum enhancement as compared to the other cases. This may be due to the reason of creation of the void by the rising bubbles while flowing along the fluid which is to be filled by the surrounding fluid thus creating turbulence in the flowing fluid causing more heat to be carried out from the surfaces by the cooling fluid. Moreover, it has been found from the earlier studies that as the number of air bubbles injected increases, the heat transfer rate also increases. The air bubble injected at the tube inlet also enhanced the heat transfer rate, but was less than the previous case discussed but more than the case where no air bubble is injected. This may be due to the fact that the rising air bubbles create more turbulence than the air bubbles entering along the fluid at the tube inlet. Moreover air bubbles injected throughout the tube have more number of air bubbles than the air bubbles injected at the tube inlet and thus less turbulence is created. From the figures 3 & 4, it is shown that the heat transfer rate increases with the increase in Reynolds number. Moreover, figures 3 & 4 also show that the injection of air bubbles throughout the tube gave maximum heat transfer rate followed by the case of air bubble injection at the tube inlet and the case of no air bubble injection. The enhancement in the heat transfer rate at 0.1% v/v and 0.2% v/v v of Al_2O_3 nanoparticles in the water base fluid was found to be 23-38% and 25-40%, respectively in case of injection of air bubbles throughout the tube w.r.t the case of no air bubble injection. The air bubble injection at the tube

inlet for 0.1% v/v and 0.2% v/v v of Al_2O_3 nanoparticles in the water base fluid enhanced the heat transfer rate by 18-28% and 20-30%, respectively w.r.t the case of no air bubble injection. This enhancement takes place at different Reynolds number under which the experiment was performed.

From the figures 5 & 6, it is shown that the heat transfer rate increases, as if we increase the temperature of the hot fluid keeping the flow rate of hot and cold fluid to be constant at 3.5lpm. This is because of increase in the temperature difference between the hot fluid and the cold fluid, which increases the heat transfer rate. Heat transfer rate found to be enhanced maximum in case, where air bubbles were injected throughout the tube followed by the air bubble injection at tube inlet and then least heat transfer rate value was found in the case, where no air bubble injection was done. Since the enhancement in heat transfer characteristics varies linearly with the volumetric concentration of nanofluid, the 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid gave more enhancement in heat transfer rate than 0.1% v/v of Al_2O_3 nanoparticles in the water base fluid.

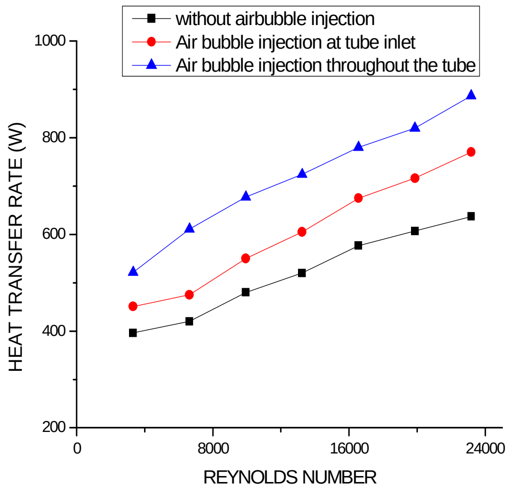

Figure 3: Heat Transfer Rate vs Reynolds Number at 0.1% v/v

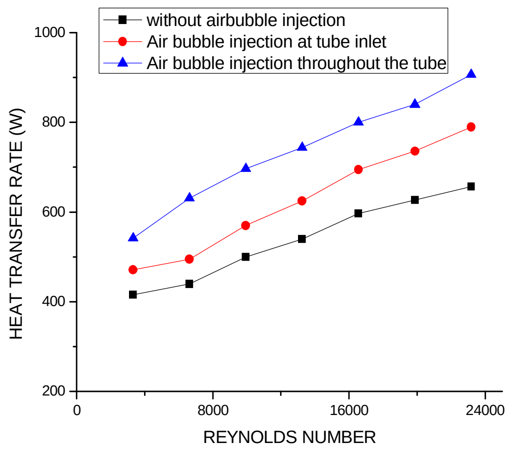

Figure 4. Heat Transfer Rate vs Reynolds Number at 0.2% v/v

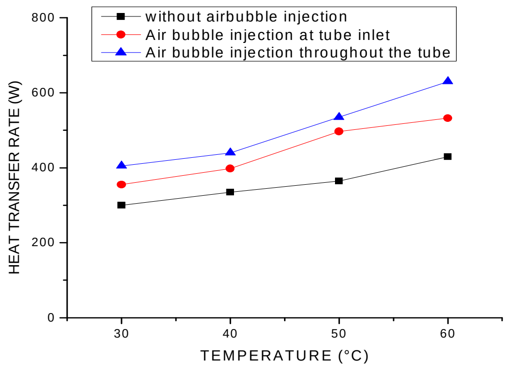

Figure 5: Heat Transfer Rate vs Temperature at 0.1% v/v

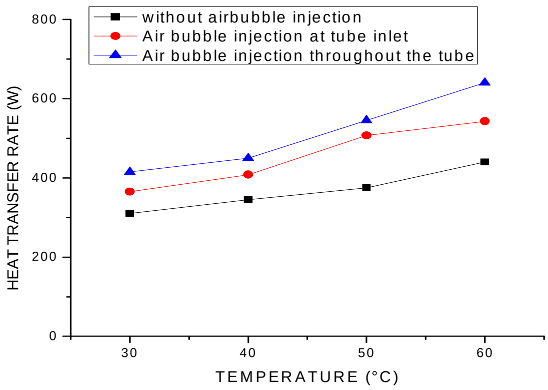

Figure 6: Heat Transfer Rate vs Temperature at 0.2% v/v

5.2 Effect on the Effectiveness

Effectiveness indicates the performance of the heat exchanger that how much the heat exchanger is effective for a specific purpose. It is the ratio of actual heat transfer to the maximum possible heat transfer by the given heat exchanger. So, more the heat transfer rate more will be the effectiveness of the heat exchanger. From the figures 7 & 8, it is shown that the effectiveness increases with the increase in Reynolds number. Moreover, figures 7 & 8 also show that the injection of air bubbles throughout the tube gave maximum effectiveness followed by the case of air bubble injection at the tube inlet and the case of no air bubble injection. The enhancement in the effectiveness at 0.1% v/v and 0.2% v/v v of Al_2O_3 nanoparticles in the water base fluid was found to be 25% to 36% and 27% to 38%, respectively in case of injection of air bubbles throughout the tube (case3). The air bubble injection at the tube inlet (case 2) for 0.1% v/v and 0.2% v/v v of Al_2O_3 nanoparticles in the water base fluid enhanced the effectiveness by 20-26% and 22-28% respectively. This enhancement takes place at different Reynolds number under which the experiment was performed.

From the figures 9 & 10, it is shown that the effectiveness increases, as if we increase the temperature of the hot fluid keeping the flow rate of hot and cold fluid to be constant at 3.5lpm. This is because of increase in the temperature difference between the hot fluid and the cold fluid, which increases the heat transfer rate and ultimately effectiveness also increases. Effectiveness found to be enhanced maximum in case, where air bubbles were injected throughout the tube followed by the air bubble injection at tube inlet, and then least effectiveness value was found in the case, where no air bubble injection (case 1) was done. Since the enhancement in heat transfer characteristics varies linearly with the

volumetric concentration of nanofluid, the 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid gave more enhancement in effectiveness than 0.1% v/v of Al_2O_3 nanoparticles in the water base fluid.

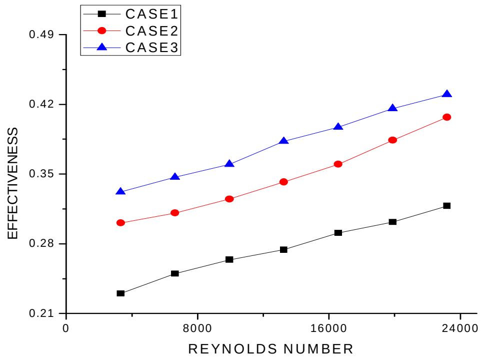

Figure 7: Effectiveness vs Reynolds Number at 0.1% v/v

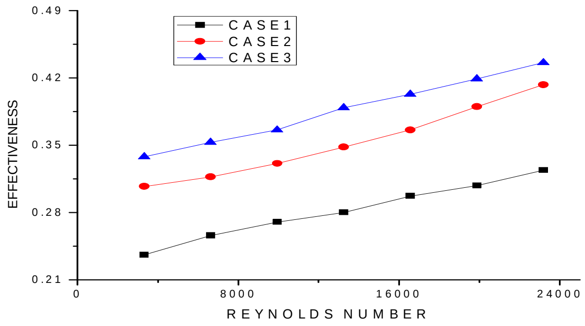

Figure 8: Effectiveness vs Reynolds Number at 0.2% v/v

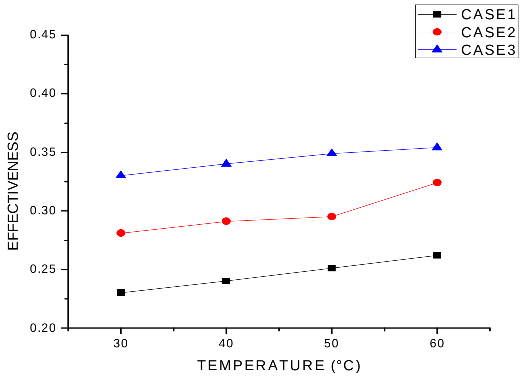

Figure 9: Effectiveness vs Temperature at 0.1% v/v

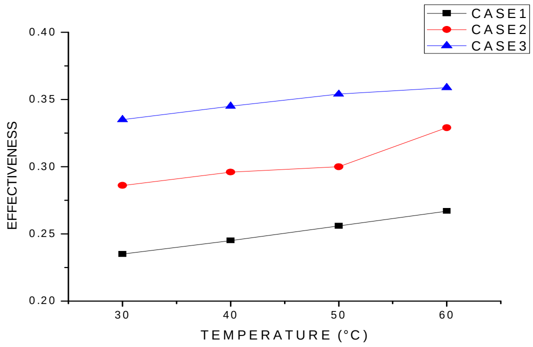

Figure 10: Effectiveness vs Temperature at 0.2% v/v

6. CONCLUSIONS

Following conclusions were made as per the above study

- Air bubble injection is one of the promising and inexpensive techniques that can reasonably enhance the thermal performance of heat exchangers.
- When the air bubbles were allowed to pass throughout the tube, the heat transfer rate found to be enhanced by 23-38% and 25-40%, respectively at 0.1% v/v and 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid w.r.t the case, when air bubbles were not injected. For the air bubble injection at the tube inlet, the heat transfer rate found to be enhanced by 18-28% and 20-30% respectively at 0.1% v/v and 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid w.r.t the case when air bubbles were not injected.
- When the air bubbles were allowed to pass throughout the tube, the effectiveness found to be enhanced by 25%-36% and 27%-38%, respectively at 0.1% v/v and 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid w.r.t the case when air bubbles were not injected. For the air bubble injection at the tube inlet, the effectiveness found to be enhanced by 20-26% and 22-28%, respectively at 0.1% v/v and 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid w.r.t the case, when air bubbles were not injected.
- Both the heat transfer rate and the effectiveness also found to be enhanced when the temperature of the hot fluid was increased by keeping the flow rate of both the heat transfer fluids to be constant. Both the heat transfer characteristics found to be enhanced maximum in case of injection of air bubbles throughout the tube, which is followed by the cases of air bubble injection at the tube inlet and no air bubble injection, respectively. Since the enhancement in heat transfer characteristics varies linearly with the volumetric concentration of nanofluid, the 0.2% v/v of Al_2O_3 nanoparticles in the water base fluid gave more enhancements in heat transfer characteristics than 0.1% v/v of Al_2O_3 nanoparticles in the water base fluid.

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